

## SUBSTITUTE SPECIFICATION

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TEMPERATURE COMPENSATED BANDGAP VOLTAGE REFERENCECROSS REFERENCE TO RELATED APPLICATIONS

This application is based on and claims priority of U.S. provisional patent application Serial No. 60/441,063, filed January 17, 2003, entitled TEMPERATURE  
5 COMPENSATED BANDGAP VOLTAGE REFERENCE, the entire disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention is directed to a temperature compensated bandgap voltage reference.

10 Figure 1 shows how a reference voltage based upon  $V_{be}$  of a bipolar transistor can be obtained. The current source  $I$  is provided in the emitter path of a bipolar transistor. A plurality of current sources can be provided each coupled to an FET of varying size to provide current sources of different magnitude, e.g.,  $I$ ,  $10I$ , etc. as shown.

15  $V_{be}$  of a bipolar transistor decreases with increasing temperature in a well-known fashion. See Fig. 3. It is also known that a current mirror can be used to obtain a voltage representative of proportional to  $\Delta V_{be}$  i.e., the difference between the  $V_{be}$  of two bipolar transistors. Figure 2 shows such a current mirror circuit.  $\Delta V_{be}$  is equal to  $V_{be2}$  minus  $V_{be1}$  and  $\Delta V_{be}$  is equal to  $kt/q \ln NI/I$ .  $\Delta V_{be}$  depends upon the  
20 ratio of the currents of the current sources as well as the temperature. In particular,  $\Delta V_{be}$  increases with temperature. See Fig. 3. By combining the two circuits, it is possible to compensate  $V_{be}$  of a first transistor with  $\Delta V_{be}$  obtained via two other transistors Q1 and Q2, to obtain a substantially constant reference voltage  $V_{ref}$  as

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shown in Fig. 3. In particular,  $V_{ref}$  is equal to a constant A times  $V_{be}$  plus a constant B times  $\Delta V_{be}$ .

### SUMMARY OF THE INVENTION

5 The invention provides a new implementation of a  $V_{be}$  bandgap voltage reference that sums  $V_{be}$  and  $\Delta V_{be}$  to obtain a substantially constant temperature independent voltage reference. The circuit uses a current mirror for  $\Delta V_{be}$  and a bipolar transistor to provide  $V_{be}$ . A comparator is implemented as a differential amplifier and receives inputs proportional to  $V_{be}$  and  $\Delta V_{be}$ . The output of the comparator is coupled back to the input of the bipolar transistor that provides  
10  $V_{be}$ .

According to one aspect, the invention comprises a bandgap voltage reference circuit comprising a first circuit providing a first voltage representative of substantially proportional to  $V_{be}$  of a first bipolar transistor, a second circuit providing a second voltage  $\Delta V_{be}$  representative of substantially proportional to the difference of two  $V_{be}$  voltages of two bipolar transistors; and a comparator having  
15 respective inputs which receive voltages representative of coupled to  $V_{be}$  and  $\Delta V_{be}$  and an output coupled to the base of the first bipolar transistor whereby a voltage representative of substantially proportional to the sum of respective constants multiplying  $V_{be}$  and  $\Delta V_{be}$  is provided at the output of the comparator.

20 According to another aspect, the invention comprises a bandgap voltage reference circuit comprising a first bipolar transistor providing substantially a reference voltage  $V_{be}$ , a current mirror circuit comprising two bipolar transistors coupled in a current mirror arrangement for providing a voltage difference  $\Delta V_{be}$  comprising substantially a difference signal between the respective  $V_{be}$  voltages of  
25 the two bipolar transistors; and a comparator having respective inputs which receive voltages representative of coupled to  $V_{be}$  and  $\Delta V_{be}$  and an output coupled to the base

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of the first bipolar transistor whereby a voltage representative of substantially proportional to the sum of respective constants multiplying  $V_{be}$  and  $\Delta V_{be}$  is provided at the output of the comparator.

According to yet another aspect, the invention comprises a bandgap voltage  
5 reference circuit comprising a first circuit providing a first voltage representative of substantially proportional to  $V_{be}$  of a first bipolar transistor, a second circuit providing a second voltage  $\Delta V_{be}$  representative of substantially proportional to the difference of two  $V_{be}$  voltages of two bipolar transistors, and a comparator having respective inputs which receive voltages representative of coupled to  $V_{be}$  and  $\Delta V_{be}$   
10 and an output coupled to the base of the first bipolar transistor whereby a substantially temperature independent voltage reference is provided at the output of the comparator.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a prior art circuit for generating a reference voltage based on  $V_{be}$   
15 of a bipolar transistor;

Fig. 2 shows a prior art circuit mirror circuit for generating a voltage proportional to  $\Delta V_{be}$ ;

Fig. 3 is a graph showing the relationship of  $V_{be}$  and  $\Delta V_{be}$  and a reference voltage comprising weighted sums of  $V_{be}$  and  $\Delta V_{be}$ ;

20 Fig. 4 shows the reference voltage generating circuit according to the invention;

Fig. 5A and 5B shows waveforms of the circuit of Fig. 4; and

Fig. 6 shows a schematic diagram of an implementation of the circuit of the invention.

## 25 DETAILED DESCRIPTION OF THE INVENTION

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According to the invention, a new implementation for deriving the voltage bandgap reference  $V_{ref}$  is provided. As shown in Fig.4, a bipolar transistor Q1 provides  $V_{be}$ . The emitter of the bipolar transistor Q1 is coupled to a resistor divider comprising resistors R1 and R2. The output of the divider is provided to a comparator UI inverting input. The non-inverting input of the comparator ~~UI~~ UI is provided to the voltage source comprising  $\Delta V_{be}$ , which may be generated by the circuit of Fig. 2 . The output of the comparator is provided back to the input  $IN'$ . This results in the following equations:

$$IN- = (IN' - V_{be})x \frac{R_2}{R_1 + R_2}$$

$$\Delta V_{be} = (IN'_{\Delta V_{be}} - V_{be})x \frac{R_2}{R_1 + R_2}$$

$$IN' = OUT$$

$$OUT = IN'_{\Delta V_{be}} \text{ (from Fig. 5B)}$$

$$IN'_{\Delta V_{be}} = V_{be} + \frac{R_1 + R_2}{R_2} \Delta V_{be}$$

$$IN'_{\Delta V_{be}} = OUT = V_{be} + \frac{R_1 + R_2}{R_{11}^2} \Delta V_{be}$$

The output of the comparator is shown in Figs. 5A and 5B versus  $IN-$  and  $IN'$ , respectively. Figure 5A shows the output versus  $IN-$  i.e., versus the input at the inverting input of the comparator. Figure 5B shows the output versus  $IN'$ , i.e., versus the input to the transistor Q1 providing the  $V_{be}$  reference voltage. Since the output of the comparator is coupled to the input  $IN'$ , the output equals  $V_{be} + (R_1 +$

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$R2/R1 \Delta V_{be}$ . Accordingly, the output voltage is a constant voltage equal to  $V_{be}$  plus a constant times  $\Delta V_{be}$ . With the appropriate selection of resistors R1 and R2, the output can remain constant.

5 Figure 6 shows a complete circuit implementation where a current mirror circuit has been substituted for  $\Delta V_{be}$  in Fig. 4. In addition, the comparator has been implemented by FETs Q2, Q3 and Q4 serving as a differential amplifier. The inputs IN- and IN+ are provided respectively at the sources of transistors Q2 and Q3 and the output OUT =  $V_{REF}$  is provided at the source of transistor Q4.  $\Delta V_{be}$  is provided by the current mirror across the gates of the transistors Q2 and Q3. In Fig. 6, a voltage  
10 divider comprising resistors R3 and R4 is provided.

$$V_{out'} = V_{out} \left( \frac{R_3 + R_4}{R_3} \right)$$

In this way, the circuit can generate a reference voltage Vout' that is a multiple of Vout. This is important in applications where a 1.25V reference voltage is too low.

15 Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. Therefore, the present invention should be limited not by the specific disclosure herein, but only by the appended claims.